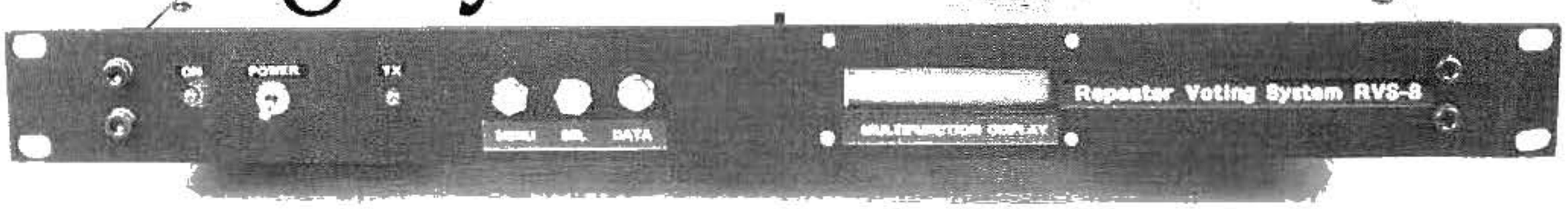
By Dwayne L. Kincaid, WD8OYG

A Microprocessor-Controlled Repeater Voting System: The RVS-8



You can add this flexible voting system to virtually *any* repeater!

Voting systems are used on repeaters that have more than one receiver. To help cover a repeater's fringe areas, remote (or satellite) receivers are placed some distance (usually several miles) away from the main repeater site and linked to it by UHF radio or telephone lines. The voter at the main site compares the audio from each receiver and selects the one with the best signal-to-noise ratio (S/N) to be retransmitted by the repeater.

The RVS-8 voter merges a microprocessor with an audio-noise-based, S/N-converting circuit to produce an eight-channel, full-featured, easy-to-use, flexible voter that interfaces to virtually *any* repeater.

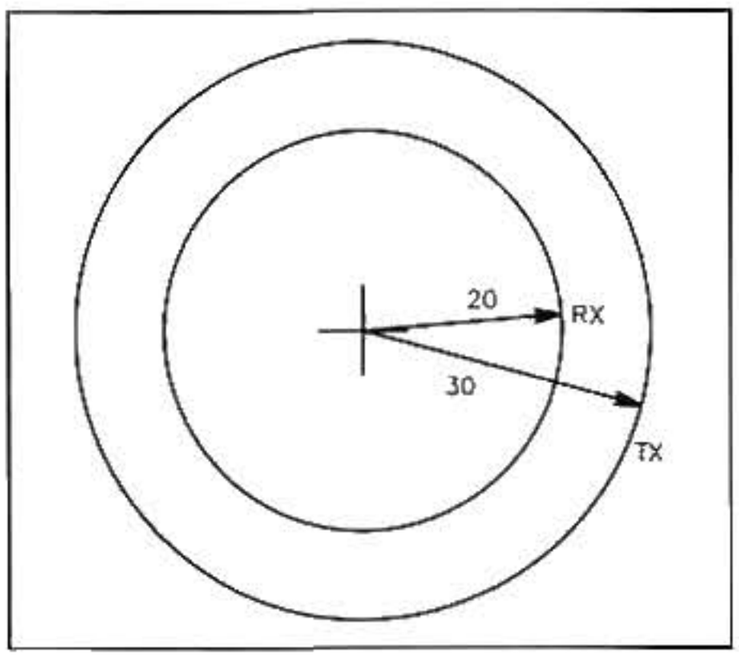


Figure 1—Typical repeater site with no remote receivers.

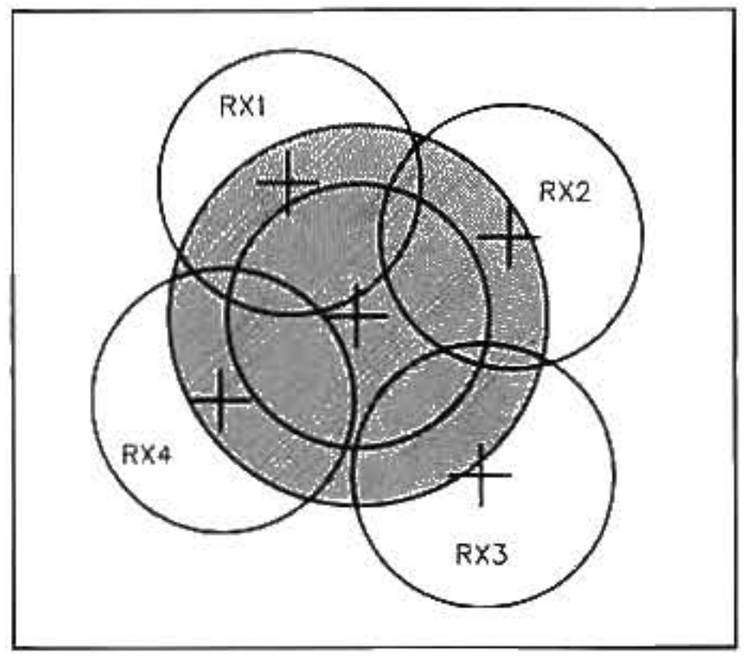


Figure 2—Repeater site equipped with multiple remotely located receivers.

Some Background

A typical repeater's coverage area is shown in Figure 1. This repeater has the transmitter and receiver at the same site and has no remote receivers. The transmitter's coverage area is shown greater (30 miles) than that of the receiver's (20 miles) because today's repeaters are built with higher-power transmitters, usually 100 W or more output. In contrast, most mobile radios have a transmitter power of 50 W or less. The power difference between the mobile station and the repeater causes communication problems because the mobile station can hear the repeater without trouble, but when the mobile station is in a fringe area, it can't be heard by the repeater. So, more than half of the repeater's coverage area (in square miles) is unusable! The problem is worse for stations equipped with low-power hand-helds.

Figure 2 shows the same repeater equipped with four remote receivers. The shaded area represents the repeater's transmitter coverage. Now, just about all of that area is covered by at least one remote receiver. Much of the coverage area of the on-site receiver is duplicated by the remote receivers. Such overlapping coverage reduces signal loss or fading caused by the terrain and surrounding structures. With the voter selecting the best signal from all of the receivers, the repeated signal is guaranteed to be the best possible.

Our local radio club has several ever-expanding repeaters with several remote receivers connected to each repeater. We quickly found that we needed a flexible, inexpensive, easily reproducible voter that can work with many types of VHF/UHF links and different controllers. After researching the available units and not finding the features we wanted at a price we could afford, we designed our own voter: the RVS-8. Figure 3 shows how it's integrated into one of our repeater sites. If you'd like an RVS-8, PC boards, *prepro-grammed* EEPROMs and complete kits are available.[1]

Features

When we designed the voter, we packed in every possible feature we'd ever seen in a system and added some of the features of a few repeater controllers. Our voter had to be flexible enough to work with any brand of controller—no restrictions on input and output—and have the dynamic audio range and frequency response to work with just about any radio. We found that the best way to allow for maximum flexibility was to make the voter software controllable and permit *each user* to custom-select items and data using a multifunction display system.

We decided on an 8-channel unit because the 68HC11 is an 8-bit microprocessor and has several 8-bit ports. It was easier to write the software for an 8-channel unit instead of

[1]Notes appear on page 43.

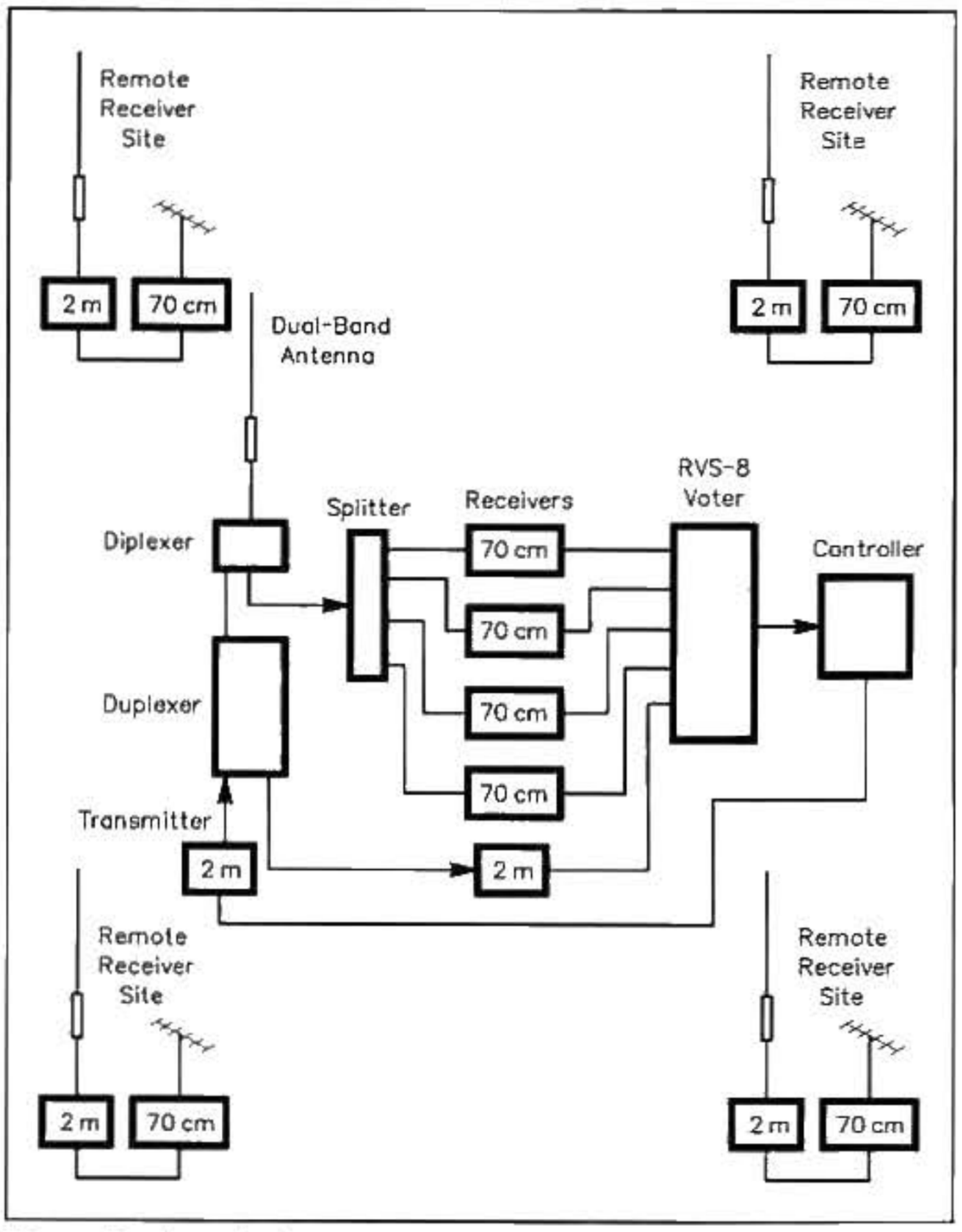


Figure 3—A typical repeater site using an RVS-8 voter.

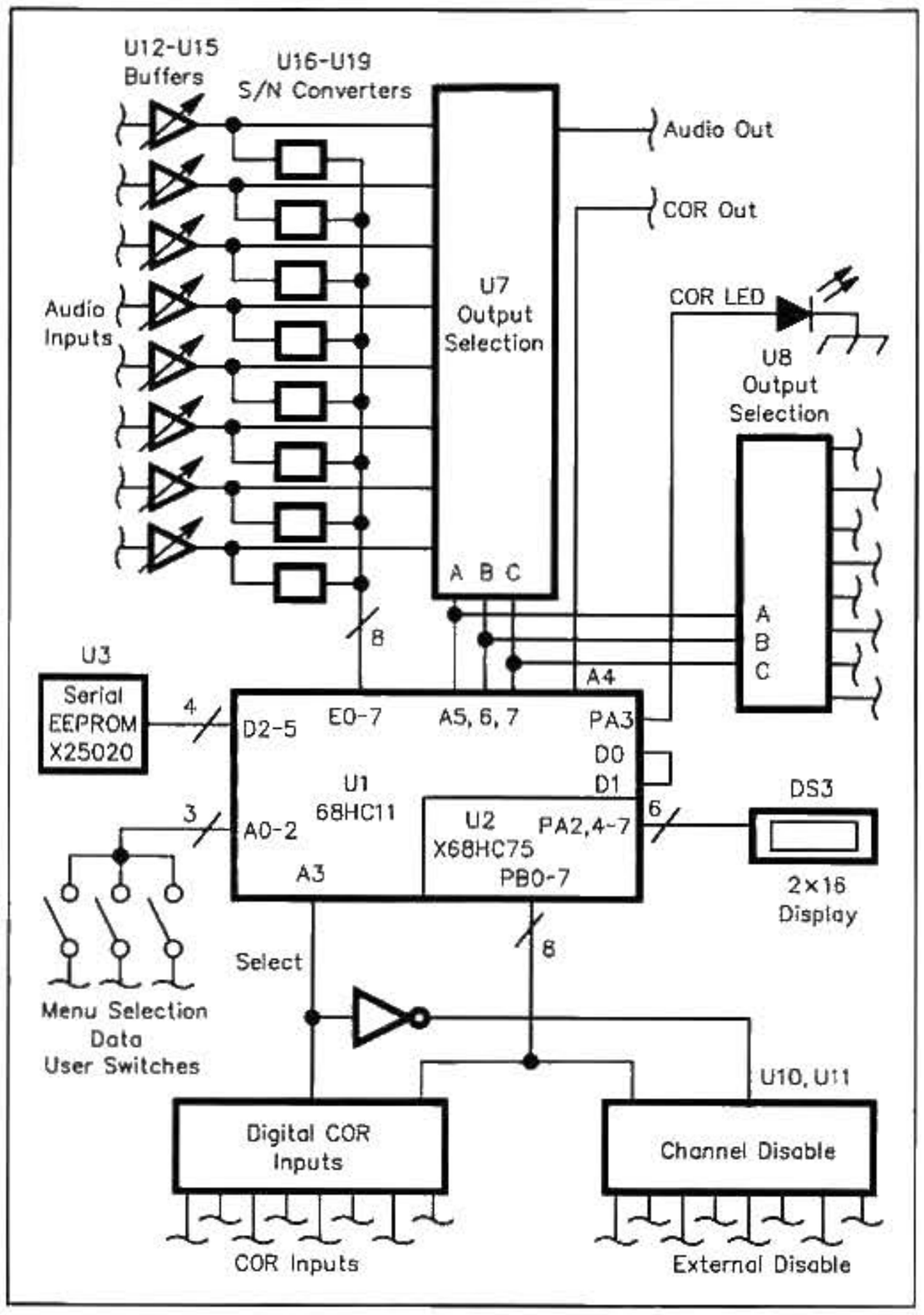


Figure 4—Block diagram of the RVS-8 voter.

trying to conform to the standard 4-channel models available. Most repeater systems may never use the full 8 channels, but they're available for expansion.

The RVS-8 has selectable active-input states. (A block diagram of the RVS-8 is shown in Figure 4; Figure 5 is the schematic.) Too many times we'd been frustrated trying to interface two radios having different carrier-operated relay (COR) active states. One receiver always seemed to need an active-high voltage and the other would only deliver an active-low voltage, or ground a transistor when active. The RVS-8 eliminates such frustration by including *programmable states* for *all* individual input controls. This includes the digital COR and external disable inputs. Each of the 16 input channels can be configured to be active-high or active-low. The user settings are stored in nonvolatile, serial, electrically erasable, programmable, read-only memory (EEPROM) to retain the information even if power is removed.

The display (DS3) gives you an inside view of what's happening with the repeater system. In other systems we've seen, a user gets an indication of only which receiving site is selected and whether or not the output COR is active. The RVS-8's display gives a lot more than that! In addition to a menu that displays which channel is currently voted (selected), there's a menu that displays which CORs are currently active. This tells you which sites are active. A few bells and whistles were added just for the fun of it. The RVS-8 has menus that display the most- and least-active channels. Because the microprocessor makes the decisions on which channel to select, it can also keep records of that. It stores the identity of the last 100 sites it voted and continually calculates which one was most and least voted. This is a neat feature if you need to measure site activity. Another menu lets you see the number of hits (out of the last 100) for each channel.

A great feature is the S/N display. Because the voter gets a digital number representing the S/N, that number can be converted into decibels and displayed. You can select to view a 10-element bar graph (10 dB per element) or see the actual number in decibels (in 5-dB increments). This feature turns the voter display into an S-meter, except that it's based on the quieting level of the S/N instead of the received signal strength. (Under normal circumstances, they're nearly equal.)

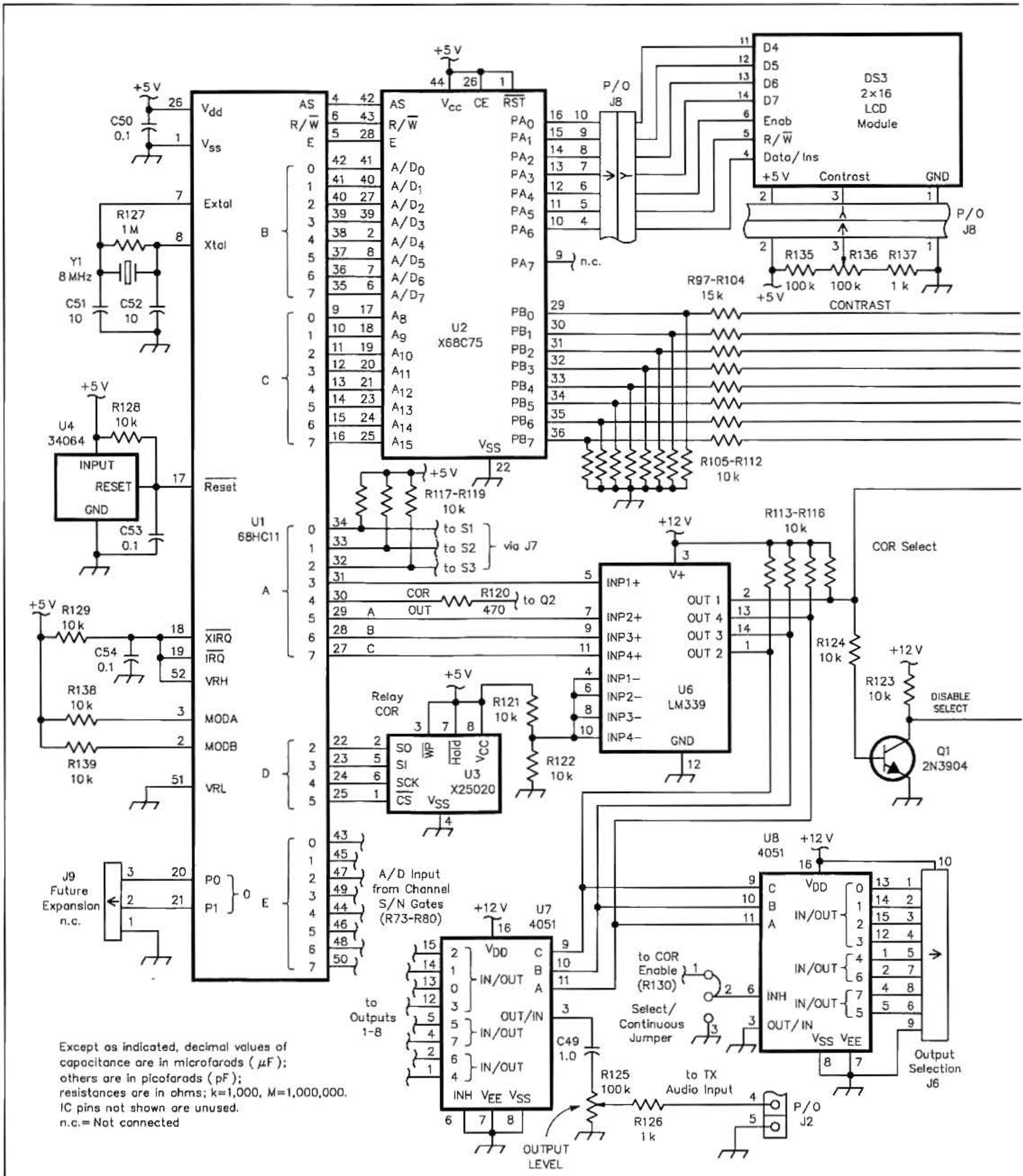
The disable system adds a lot of flexibility to the voter. One of the menus displays the currently disabled channels. With the interface, you can select and enable or disable each channel. Your selections are stored in the nonvolatile serial EEPROM. There are also eight input lines on the back panel that externally disable the corresponding channel. Of course, the external disable inputs can be programmed to be active high or low. The external disable is great if your controller has digital outputs that can be selected by DTMF tones to allow remote disabling.

The eight COR inputs (J6) can be programmed to be active high or low. The digital signal (COR squelch input) on the back panel has its own group of eight screw connections (J4). The COR inputs use a voltage reference to determine the state: 0 to 3 V is off, and 7 to 20 V is on.

The RVS-8 also has a user-selectable hysteresis level. The hysteresis level is the amount of signal required of a new channel to be selected in lieu of the active channel. Hysteresis is desirable because it keeps the voter from rapidly switching back and forth between sites when the signal is nearly equivalent at each site. Unless the audio levels are perfectly matched, it would deliver annoying audio to listeners. The hysteresis level is selectable in 1-dB steps from 0 to 20 dB. A typical setting is about 5 to 10 dB.

Circuits

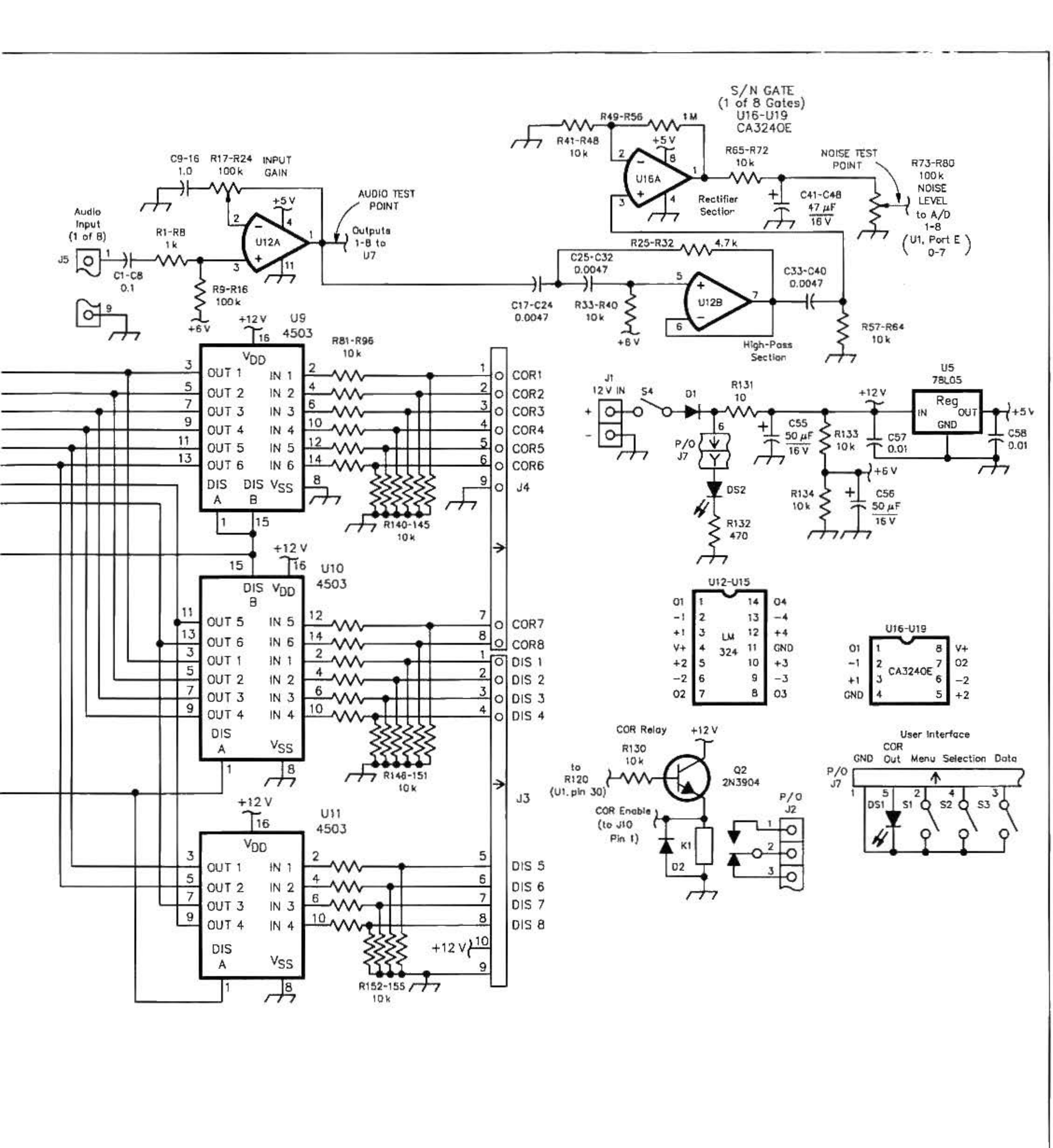
The RVS-8 can be broken down into three main sections: the S/N converters, the user interface and the microprocessor section.



Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k=1,000, M=1,000,000. IC pins not shown are unused. n.c.= Not connected

Figure 5—Schematic of the RVS-8 circuit. Unless otherwise specified, resistors are ¼-W, 5%-tolerance carbon-composition or film units. Equivalent parts can be substituted. DK part numbers are Digi-Key (Digi-Key Corp, 701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677; tel 800-344-4539, 218-681-6674; fax 218-681-3880).

D1—1N4001
D2—1N4148
DS1, DS2—Red LED
DS3—Timeline 2-line × 16-character LCD
J1—2-pin screw, panel mount
J2—5-pin screw, panel mount
J3, J6, J8, J9—10-pin DIP header, 0.1-inch spacing
J4, J5—9-pin screw, panel mount
J7—5-pin DIP header
K1—SPDT 12-V relay (DK Z721; Omron G5L-112P-PS-DC12)
Q1, Q2—2N3904
R73-R80, R125, R136—100 kΩ, PC-mount potentiometer (DK D4AA15;



Panasonic EVN-D8AA03B15)
S1-S3—SPST momentary pushbutton
S4—SPST toggle switch
U1—68HC11 microprocessor
U2—X68HC75 *programmed* port expander and EEPROM; see Note 1.
U3—X25020 256 × 8-bit SPI serial EEPROM
U4—MC34064 undervoltage sensing circuit
U5—LM78L05 3-terminal positive 5-V, 100-mA voltage regulator
U6—LM339 low-power, low offset-voltage quad comparator
U7, U8—4051 8-channel analog MUX/DEMUX
U9-U11—4503 hex noninverting three-state buffer
U12-U15—LM324 low-power quad op amp
U16-U19—CA3240E dual BIMOS op amp
Y1—8-MHz crystal
Misc: 52-pin socket; 44-pin socket; 8-pin IC sockets; 14-pin IC sockets; 16-pin IC sockets; enclosure, hardware.

Table 1
User Interface Switch Action

Menu (S1)	*Channel Switch (S2)*	*Data Switch (S3)*	*EEPROM Write*
Current voted	N/A	N/A	No
Current CORs	N/A	N/A	No
Disabled channels	Next channel	Toggles high or low	Yes
Most voted	N/A	N/A	No
Least voted	N/A	N/A	No
Hits/channel	Next channel	Reset all channels	No
COR state	Next channel	Toggles high or low	Yes
Hysteresis	N/A	0 to 20 dB	Yes
Channel S/N	Next channel	Bargraph or decibels	No
Disabled state	Next channel	Toggles high or low	Yes

Table 2
RVS-8 Connector Pin-Outs

J1-1	+12 V	J5-8	Audio In 8
J1-2	GND	J5-9	GND
J2-1	K1 NO contact	J6-1	Selection 1
J2-2	K1 common	J6-2	Selection 2
J2-3	K1 NC contact	J6-3	Selection 3
J2-4	Audio Out	J6-4	Selection 4
J2-5	GND	J6-5	Selection 5
J3-1	Disable 1	J6-6	Selection 6
J3-2	Disable 2	J6-7	Selection 7
J3-3	Disable 3	J6-8	Selection 8
J3-4	Disable 4	J6-9	GND
J3-5	Disable 5	J6-10	+12 V
J3-6	Disable 6	J7-1	GND
J3-7	Disable 7	J7-2	Menu
J3-8	Disable 8	J7-3	Data
J3-9	GND	J7-4	Selection
J3-10	+12 V	J7-5	COR LED
J4-1	COR 1	J7-6	On/Off LED
J4-2	COR 2	J8-1	Contrast
J4-3	COR 3	J8-2	GND
J4-4	COR 4	J8-3	+5 V
J4-5	COR 5	J8-4	GND
J4-6	COR 6	J8-5	Data
J4-7	COR 7	J8-6	WR
J4-8	COR 8	J8-7	D3
J4-9	GND	J8-8	D2
J5-1	Audio In 1	J8-9	D1
J5-2	Audio In 2	J8-10	D0
J5-3	Audio In 3	J9-1	GND
J5-4	Audio In 4	J9-2	n.c.
J5-5	Audio In 5	J9-3	n.c.
J5-6	Audio In 6		
J5-7	Audio In 7		

n.c. = no connection

Signal-to-Noise Converters

The foundation of the voter is its the ability to measure the noise of an audio signal and present it as an analog voltage to the microprocessor. The eight S/N converters are similar in design to those of Mark Kolber's Audio-Noise-Based Voting Circuit.[2] Like Kolber's, each S/N converter uses a separate input buffer, high-pass filter, noise rectifier and a smoothing circuit for each channel. The RVS-8 goes one step farther by allowing the output of each converter to deliver a voltage representation of the S/N. This is a 0 to 4-V signal that is read by the ADCs in the microprocessor. The higher the audio noise, the higher the ADC voltage. The microprocessor can then keep statistics on each signal and mathematically vote to see which channel to select.

The RVS-8 adds an extra two-pole high-pass filter to provide a steeper roll-off of the signal's voice components. The two-pole high-pass section rolls off frequencies below 5 kHz, and the 1-pole high-pass section provides additional roll-off of frequencies below 3 kHz. Once a channel is voted, U7 selects and passes the audio signal of the channel with the best S/N. U8 decodes and brings the selection to the back panel. This output allows for triggering an external device (such as a voice chip or repeater controller) with the selection. The selection out can be continuous or COR-activated and is chosen using a jumper. In continuous mode, the output always shows the last channel voted.

When COR is on, the output has a signal only when the COR is active. High-impedance (10-kΩ) op-amp buffers on the input don't load down the receiver—you can even use speaker audio from most receivers. A potentiometer on each channel allows adjustment of the audio-input voltage for a gain of 0 to 20 dB. This permits easy audio-level matching of multiple receivers.

Each channel is equipped with a potentiometer to adjust the "noise level" of each input. This allows each channel to be custom calibrated to provide the same noise voltage to the ADCs. The adjustment can also be used to favor a particular channel by reducing the apparent noise seen by the microprocessor. Only a voltmeter is needed for calibration. After the analog selection switch, a potentiometer (R125) adjusts the overall level of the audio sent to the transmitter. Audio-section frequency response is excellent: 0 dB from 300 to 6000 Hz. Total harmonic distortion is less than 0.5%.

User Interface

The user interface consists of three input switches (S1 to S3), a 2-line by 16-character LCD module (DS3) and the back-panel connectors. DS3 provides different information according to the menu selected. The input switches control the menu, channel and data selection presented by the LCD.

Ten menus provide information to the user (see Table 1). Pressing S1 (**MENU**) cycles the display through the menus. In certain menus, S2 (**SELECTION**) cycles the display through the channel selections. The channel selection for COR state, hits per channel, disabled channels and disabled state are tied together internally by software. If you select channel 3 in the Disable menu, you'll automatically be set to channel 3 when you switch to the COR State menu S3, the data-selection switch (**DATA**) cycles through the available choices for each channel and menu.

The back-panel connectors include **POWER, COR, AUDIO OUTPUT, DISABLE INPUT, COR INPUT, AUDIO INPUT** and **SELECTION OUTPUT**. The **POWER, COR OUT, COR IN** and **AUDIO IN** are screw type terminal blocks. The **DISABLE IN** and **SELECTION OUT** are 10-pin, right-angle DIP headers (see Table 2).

Microprocessor Section

The microprocessor, U1, is an MC68HC11A1FN. Internal to the chip are 512 bytes of EEPROM, 256 bytes of RAM for data storage, an 8-bit output port, an 8-bit input/output (I/O) port, an 8-channel, 8-bit analog-to-digital input port and an 8-bit timer port. There's also a serial port (useful for RS-232-C connections) and a high-speed serial peripheral interface (SPI) port. Because more than the 512 bytes of internal memory are needed for the RVS-8, U2—a Xicor X68C75 EEPROM and port-expansion chip—is used. It contains 8192 bytes of nonvolatile program space and an address decoder system to turn U1's two 8-bit address ports into bidirectional I/O ports.

U3, a Xicor X25020 serial EEPROM (256 bytes), stores a user's custom settings. It's connected to U1's high-speed SPI port. The EEPROM has a high life cycle of 100,000 writes per byte. This means you'd have to make more than 25 changes on the same data in the RVS-8 every day for 10 years before U3 would wear out.

One of U2's 8-bit I/O ports is used for DS3. Four bits are used for the data transfer from U1 to the LCD. Other bits set the read/write line, the data/command line and read the busy line. U2's other 8-bit I/O port is configured as an input port and used to detect digital COR and external disable inputs. U2's eight ADCs are inputs for the S/N voltage of each channel. U2's timer port controls the selected audio output, reads the user switches, controls the transmitter COR and selects either the digital CORs or external disable inputs.

The RVS-8 operates on 12 V dc. A voltage divider provides 6 V to the op-amp circuits. An on-board regulator (U5) provides U1 and the memory chips with 5 V. The primary current consumers are U1 and the memory chips (at 50 mA). The rest of the circuit draws about 40 mA, making the total current consumption less than 100 mA. U1 also needs a power supervisory circuit (U4) to provide a proper power-on sequence and to place the processor in a known reset mode when powering down. The powering-down protection is important because it keeps U1 from accidentally overwriting or erasing the EEPROM that contains the program. U4 also keeps U1 from "running away" if the supply voltage drops below 4.7 V.

Construction

Because of the relatively large number of

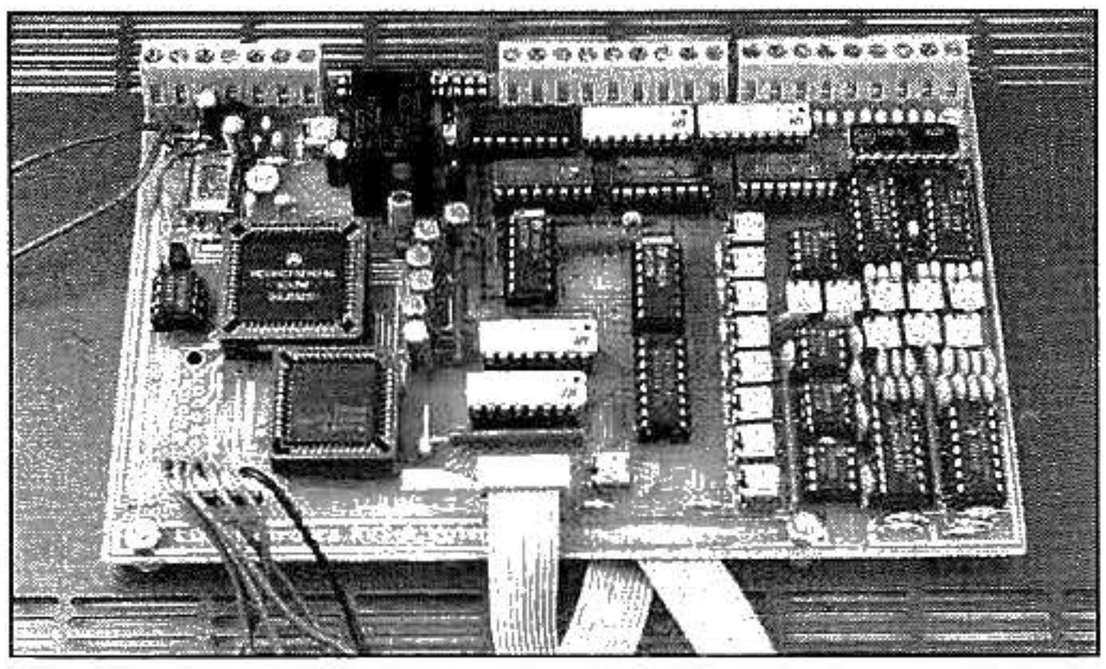


Figure 6—The RVS-8 is as attractive as it is functional.

ICs (16) in this project, I recommend using the available PC board (see Note 1). Use a 25 to 30-W soldering iron with a fine point for best results. Use sockets for all of the CMOS ICs and wear a static-conductive bracelet; these steps reduce the chance of damaging the ICs by a static discharge during handling. You could wire-wrap the circuit, but be prepared to exercise a lot of patience! There are hundreds of connections to make. If you do your own board layout, remember to use bypass capacitors (0.01 μF between power and ground) at every chip.

Because the unit will probably be installed near a repeater's transmitter, be sure to place it in a shielded enclosure. One of our installations uses a separate rack case, but the RVS-8 could also be installed in the same enclosure as the repeater's controller. The back-panel connectors and about one-half inch of the PC board can be placed through an opening in the enclosure if desired. This allows for easy interface to the 48 connections available on the panel.

DS3 uses a standard 14-pin I/O connector pin-out, but only seven lines are actually needed. I recommend running a 6-inch piece of 7 or 8-conductor ribbon cable from the PC board to the front panel. Be sure to match up the pin numbers; you can use the signal names as a double check.

The front-panel switches and LEDs connect to a DIP header on the PC board. I used stranded #22 wire for the point-to-point connections.

Software

The RVS-8 program is written in 68HC11 assembly language. Actually, there are two programs: the voter program and the display program. The voter section is interrupt driven and takes new receiver readings at a 100-Hz rate. It reads the ADCs, calculates the S/N for each channel, updates all of the internal registers and makes the voted selection, if needed. Between votes, the software takes care of user functions: switch inputs, display and the serial EEPROM (U3).

Adjustments

A few simple adjustments are needed to calibrate the input buffers, S/N converters and the transmitter audio output. If you're at the workbench, you'll need an FM receiver and a voltmeter. (An oscilloscope is helpful, but isn't necessary.) If you're at the repeater site, you'll only need a voltmeter because the receivers are already there. Preset R17 through R24, R73 through R80, and R125, to midrange before initial calibration (R136 is the **CONTRAST** pot for the LCD.)

At the workbench, set each channel to match your COR active type and state. Set the Disable menu to disable all channels except the one you're calibrating. First, apply the audio signal from a receiver to the channel being calibrated. Then, with the squelch open and no RF signal applied to the receiver, adjust the receiver's volume control and the input buffer pots (R17 through R24) to read 1 V ac (4 V P-P on a scope) at the audio test point for each channel.

With the squelch open and no RF signal applied to the receiver, adjust each noise test point (R73 through R80) to read 4 V dc. Then simply repeat the audio and noise adjustments for the other seven channels.

At the repeater site, you may have to make minor readjustments to compensate for receiver differences. You may want to temporarily connect toggle switches to the disable lines and set the hysteresis to 0 dB so you can quickly switch back and forth between sites to check for any differences in audio.

Ideally, a repeater system uses identical remote receivers and link equipment. This ensures that the audio characteristics are the same for each site. If different equipment is used, it may be necessary to place audio-shaping components (such as a 0.01-µF capacitor to ground to filter out high frequencies) in the audio lines to properly match the different audio characteristics.

On the Air Results

The "bad" thing about using voters is that when they work properly, you can't tell they're there! We now use three RVS-8s in the southern Maryland area and all have had the same transparent response. What more can we say! Installation was a breeze: The units were tested and set up on the bench, then placed right on the air. Only slight adjustments were made at the repeater sites.

Acknowledgments

Many thanks to the members of the Southern Patuxent Amateur Radio Club for providing the repeater testbeds and feedback for this project. Special thanks to Gene Tehansky, AA3AV, for his contributions and assistance with the assembly language and PC board layout. Also thanks to Gene Talley, N3JTO, and Bron Kidwell, N3AGB, for their assistance with the prototypes and testing. And thanks to my wife, Jennifer, for her patience, understanding and support with yet another project.

Notes

[1]U2 must be programmed properly to operate correctly. A complete kit of parts including a PC board, a 68HC11 and *programmed* X68HC75 (less power supply, enclosure and hardware) are available for $179, plus $8 (US, Canada and Mexico) shipping from LDG Electronics, 1445 Parran Rd, St Leonard, MD 20685, tel 410-586-2177; MasterCard and Visa charge cards accepted. Foreign orders add $20 for postage. Maryland residents must add 5% sales tax. A drilled and etched PC board only is available for $30, plus $5 shipping. A group of three ICs (a 68HC11, a *programmed* X68HC75, and an X25020) are available for $55, plus $5 shipping. Source code and a detailed software flowchart are available from LDG Electronics for an SASE (with two First-Class stamps) and a postpaid disk mailer with a 3.5-inch disk. The source-code file (**RVS8.SRC**) can be found on the Internet (ftp to **oak. oakland.edu, dir pub/hamradio/arrl**) and on the ARRL BBS (860-594-0306). A PC-board template package is not available.

[2]Mark Kolber, WB2WHC, "An Audio-Noised-Based Voting Circuit," *QST*, Oct 1992, pp 24-26

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New Products

MOBILE ANTENNA

◊ NCG's Comet CA-HV antenna can be set to transmit on two HF bands (choices are 40, 20, 15 or 10 meters) and also operate on 6 and 2 meters. The antenna uses top- and side-mounted resonating coils for the HF bands, and the antenna operates as a 1/4-wave radiator on 6 meters and a 5/8-wave on 2 meters. You can also use the antenna without the HF resonating coils for 6 and 2 meters only. The CA-HV can be used with the Comet CF-S30 duplexer with HF/VHF rigs such as the ICOM IC-706 or the Alinco DX-70T. Maximum height with the 40-meter resonating element installed on top is 6 feet 4 inches, and the mast has a fold-over hinge to lower the antenna to garage the vehicle. The CA-HV is available through Amateur Radio dealers. For more information, contact NCG, 1275 N Grove St, Anaheim, CA 92806; tel 714-630-4541; fax 714-630-7024. QST